ANL-7617
Reactor Technology

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

# OPERATING EXPERIENCE WITH THE EBR-II ROTATING-PLUG FREEZE SEALS

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EBR-II Project

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## ABSTRACT

The EBR-II rotating-plug freeze seals have fulfilled the design requirements of acting as a blanket-gas seal while (a) providing a solid mechanical seal during reactor power runs and (b) providing a movable liquid seal during fuel handling.

The operation of the freeze seals has not been trouble-free, however. In 1962, before the primary tank was filled with sodium, the large and small rotating plugs were removed and the freeze-seal system was modified extensively. In 1966, the 200 blade heaters in the large and small rotating plugs, which were clad with Type 304 stainless steel, were replaced with heaters clad with Type 405 stainless steel.

The rotational ability of the rotating plugs gradually deteriorated to the point where movement of the plugs became exceedingly difficult. In 1966, vertical access holes were drilled through the body of the large plug and the small plug into the air side of the seal troughs. The top levels of the seal troughs were found to contain large amounts of compacted dross, which was removed by coring and brush cleaning. After the seal-cleaning operations were completed, both seal troughs were returned to their normal levels by replenishment with fresh seal alloy.

Since that time, the seals have operated quite reliably. Periodic brush cleaning of the seals has been required to remove accumulated dross. This maintenance has been bothersome, but has not seriously detracted from reactor operating time.

# I. INTRODUCTION

## A. EBR-II Description

The EBR-II facility was originally designed as a fast-breeder-reactor engineering demonstration plant. Currently it is the USAEC's prime facility for irradiation of fuel samples and cladding and structural materials in the Liquid Metal Fast Breeder Reactor Program.

The EBR-II facility comprises four plants: reactor plant, sodium boiler plant, power plant, and Fuel Cycle Facility. The Fuel Cycle Facility was used until recently to demonstrate the on-site reprocessing and refabrication of EBR-II fuel; now it is used primarily for examination and handling of irradiated samples. The EBR-II core is fueled with uranium-235 but is designed to operate also with plutonium. References 1 and 2 contain a detailed description of the EBR-II facility; Fig. 1 shows a cutaway view of the reactor building.

The reactor, the primary sodium pumps and piping, the heat exchanger, and the fuel-handling system (shown in Fig. 2) are all contained in a primary tank 26 ft in diameter by 26 ft in height and are submerged in 88,000 gal of liquid sodium. This "submerged" concept has a number of practical advantages. Some of these are: (a) The primary-coolant-system piping need not be leaktight, since any leakage is internal; (b) the primary tank can be of relatively simple design and thus have a high degree of integrity; (c) fuel elements can be replaced rather quickly to minimize downtime, and can be stored in the tank where they are cooled by the sodium until removed for processing; (d) the heat capacity of the large mass of sodium prevents rapid changes in temperature; and (e) essentially all the radioactivity in the plant is confined to the primary tank.

## B. General Description of Rotating Shield Plugs

Two rotating shield plugs, identified as the large and small rotating plugs, are located in the top part of the primary-tank cover. The large plug is centrally mounted in the primary-tank cover with its vertical axis coinciding with that of the reactor core. This position reduces the effects of differential thermal expansion of the primary-tank cover, which occurs because of a temperature range from 700°F within the primary tank to room temperature on the top face of the large rotating plug; the central position thus helps ensure alignment of vital external fuel-handling components with the subassemblies within the reactor vessel. The small plug is positioned eccentrically within the large plug with its vertical axis offset 15.213 in. from that of the large plug (as shown in Fig. 3). Both plugs rotate about their vertical axes during removal and replacement of core subassemblies.

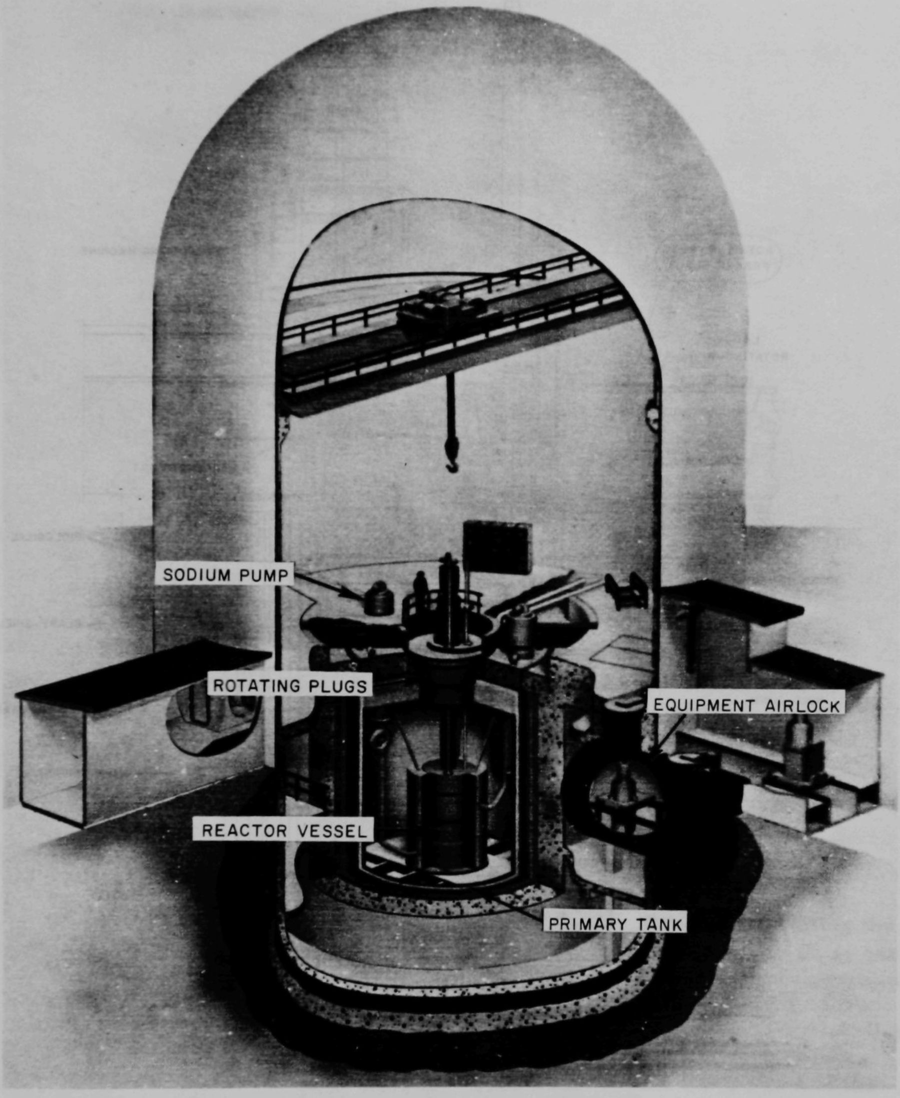


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Fig. 1. Cutaway View of Reactor Building

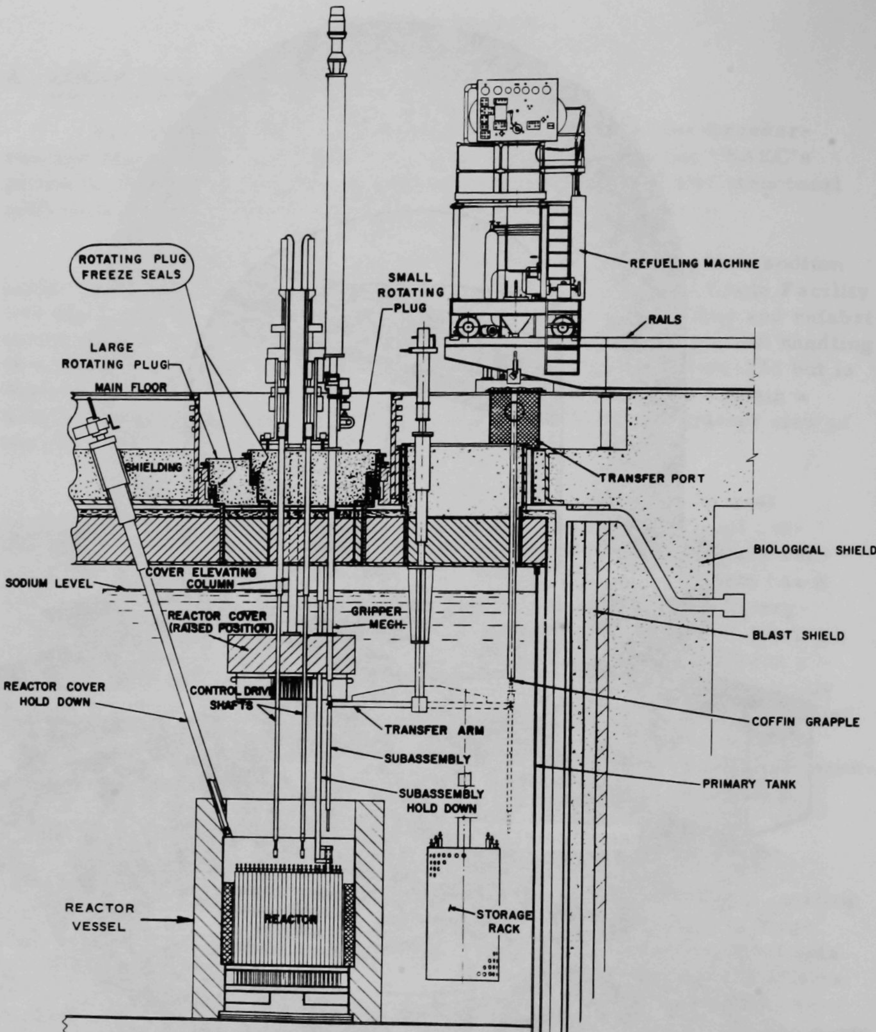


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Fig. 2. Primary Tank Showing Reactor and Fuel-handling Mechanism

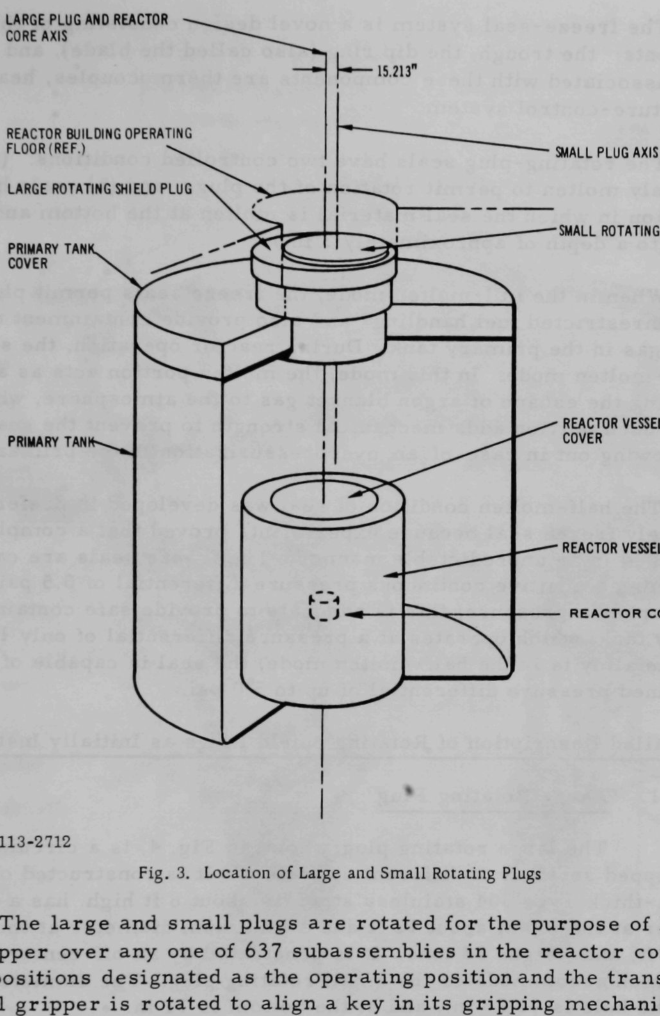


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Fig. 3. Location of Large and Small Rotating Plugs

The large and small plugs are rotated for the purpose of locating the fuel gripper over any one of 637 subassemblies in the reactor core or at one of two positions designated as the operating position and the transfer position. The fuel gripper is rotated to align a key in its gripping mechanism with a slot on each subassembly. With this arrangement, each subassembly location and the operating and transfer positions can be identified by three angular coordinates corresponding to the angular positions of the two plugs and the fuel gripper. The repeatable accuracy of the positioning system is sufficient to ensure proper coupling between the gripper mechanism and the subassembly. The plugs are also used as a neutron and gamma shield, which allows personnel access around the top of the containment vessel at all times. The plugs additionally act as a thermal barrier between the bulk sodium at 700°F and the reactor operating floor, which is normally at 72°F.

The freeze-seal system is a novel design consisting of three principal components: the trough, the dip ring (also called the blade), and the seal alloy. Associated with these components are thermocouples, heaters, and the temperature-control system.

The rotating-plug seals have two controlled conditions: (a) seals completely molten to permit rotation of the plugs, and (b) seals half molten, a condition in which the seal material is molten at the bottom and frozen at the top (to a depth of approximately 3 in.).

When in the full-molten mode, the freeze seals permit plug rotation during unrestricted fuel handling* and also provide containment of the argon blanket gas in the primary tank. During reactor operation, the seals are in the half-molten mode. In this mode, the molten portion acts as a gas seal, preventing the escape of argon blanket gas to the atmosphere, while the upper frozen portion adds mechanical strength to prevent the seal alloy from blowing out in case of an overpressurization in the primary tank.

The half-molten condition of seal was developed in preference to a completely frozen seal because experiments proved that a completely frozen seal leaked in an unpredictable manner. The freeze seals are capable of maintaining a positive continuous pressure differential of 0.5 psi with respect to atmospheric pressure; this is adequate to provide safe containment of the primary tank, which operates at a pressure differential of only 1 in. of water. When the alloy is in the half-molten mode, the seal is capable of maintaining a sustained pressure differential of up to 5.0 psi.

## C. Detailed Description of Rotating Shield Plugs as Initially Installed

### 1. Large Rotating Plug

The large rotating plug, shown in Fig. 4, is a circular cylinder with stepped sections of different diameters. It is constructed of welded, 0.75-in.-thick Type 304 stainless steel, is about 8 ft high, has a maximum diameter at the top of about 12 ft and a minimum diameter at the bottom of about 9 ft, and weighs 58 tons. It is penetrated by an off-center, stepped hole, which accommodates the small rotating plug. The diameter at the top of the hole is 91.25 in., and at the bottom is 71 in.

The bottom portion of the large rotating plug is filled to a depth of approximately 32 in. with 3/8-in.-dia steel shot. The middle portion is filled with a 3-in. layer of foam-glass insulation covered with fiber-glass cloth, then another 3-in. layer of foam-glass insulation covered with a sheet of 0.031-in.-thick stainless steel sheeting. The upper portion of the plug is filled with high-density concrete to a depth of approximately 48 in. to act as biological shielding.

*Unrestricted fuel handling includes transfers in and out of the reactor core as well as transfers between the reactor storage basket and the fuel-unloading machine.

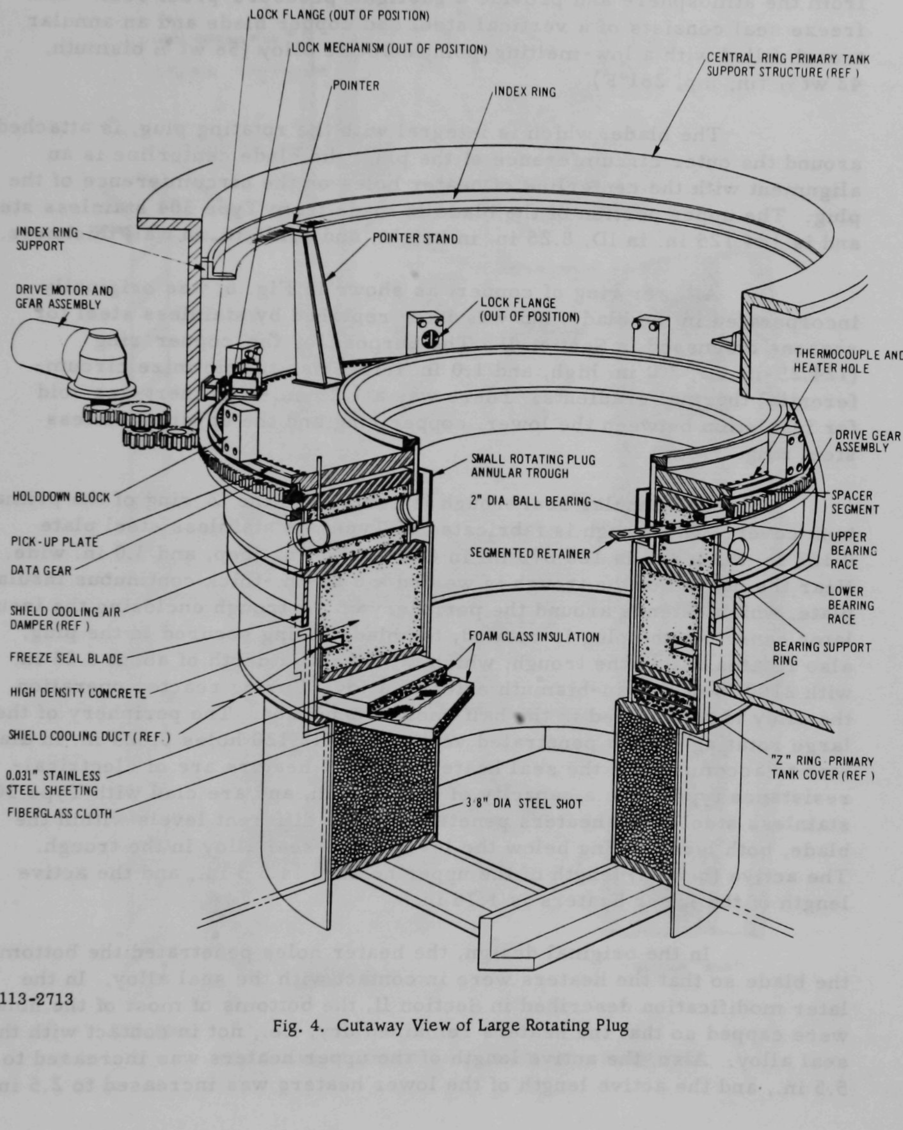


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Fig. 4. Cutaway View of Large Rotating Plug

A freeze seal, shown in Fig. 5, is located around the periphery of the large rotating plug to seal the primary-system argon-gas blanket from the atmosphere and provide a gastight, pressure-proof seal. The freeze seal consists of a vertical steel and copper blade and an annular trough filled with a low-melting-point eutectic alloy (58 wt % bismuth, 42 wt % tin; mp, 281°F).

The blade, which is integral with the rotating plug, is attached around the outer circumference of the plug; the blade centerline is an alignment with the centerline of heater holes on the circumference of the plug. The upper portion of the blade is made from Type 304 stainless steel and is 124.125 in. in ID, 8.25 in. in height, and 1.125 in. in wall thickness.

A lower ring of copper, as shown in Fig. 6, was originally incorporated in the blade, but was later replaced by stainless steel for reasons discussed in Section II. The purpose of the copper ring (124.25-in. ID, 2.0 in. high, and 1.0 in. thick) was to minimize circumferential thermal gradients. There was a 1.25-in.-high inert-gas void for insulation between the lower, copper ring and the upper, stainless steel ring.

The annular seal trough is secured to the Z ring of the primary-tank cover. The trough is fabricated of Type 304 stainless steel plate 0.188 in. thick and is 128.875 in. in OD, 10.750 in. deep, and 3.0 in. wide. Near the bottom of the trough is welded a 0.25-in.-thick continuous insulator plate, which extends around the periphery of the trough enclosing the insulator cans. As the plug is rotated, the blade, being secured to the plug, also rotates within the trough, which is filled to a depth of about 8.25 in. with 2100 lb of the tin-bismuth eutectic alloy. During reactor operation, the alloy is maintained in the half-molten condition. The periphery of the large rotating plug is penetrated vertically with 120 holes 0.625 in. in diameter to accommodate the seal heaters. These heaters are of electrical-resistance type, have a capacity of 350 W each, and are clad with Type 304 stainless steel. The heaters penetrate to two different levels within the blade, both levels being below the level of the seal alloy in the trough. The active (heated) length of the upper heaters is 3.3 in., and the active length of the lower heaters is 1.75 in.

In the original design, the heater holes penetrated the bottom of the blade so that the heaters were in contact with the seal alloy. In the later modification described in Section II, the bottoms of most of the holes were capped so that the heaters remained dry, i.e., not in contact with the seal alloy. Also, the active length of the upper heaters was increased to 5.5 in., and the active length of the lower heaters was increased to 2.5 in.

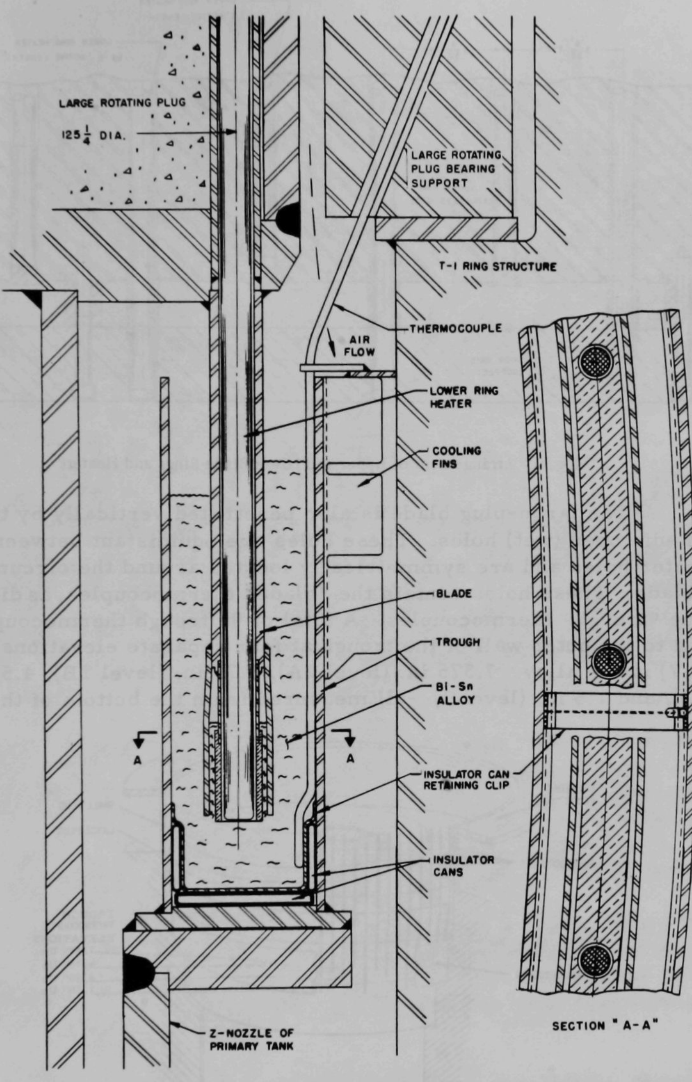


Fig. 5. Large-rotating-plug Freeze Seal before Modification

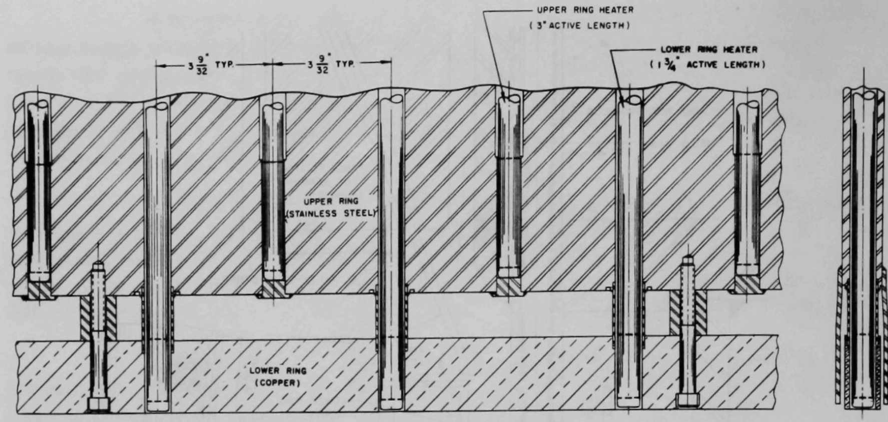


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Fig. 6. Arrangement of Upper and Lower Blade Rings and Heaters

The large-plug blade is also penetrated vertically by twelve 0.25-in.-dia open (wet) holes. These holes are equidistant between two adjacent heater holes and are symmetrically located around the circumference of the blade. These holes contain the "blade" thermocouples, as distinguished from the "trough" thermocouples. A total of 96 trough thermocouples are attached to the outer wall of the trough at four separate elevations (as shown in Fig. 7) in the alloy: 7.375 in. (level 1A), 6.75 in. (level 1B), 4.5 in. (level 2), and 1.5 in. (level 3)--all measured from the bottom of the trough.

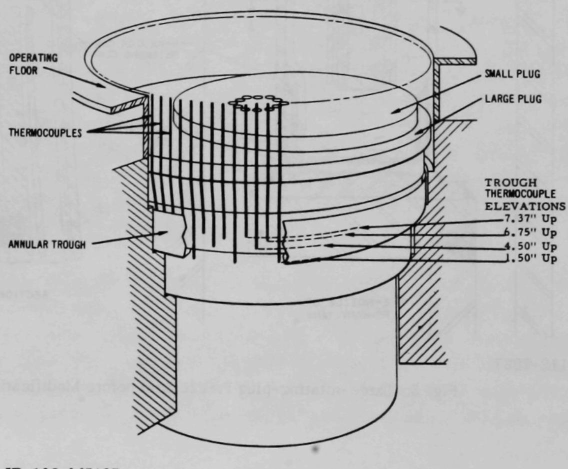


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Fig. 7. Trough Thermocouple Locations of Large Plug

## 2. Small Rotating Plug

The small rotating plug, as shown in Fig. 8, is also a cylinder with stepped sections of different diameters. Like the large plug, it is constructed of welded, 0.75-in.-thick Type 304 stainless steel. It is approximately 8 ft high, has a maximum diameter at the top of approximately $7\frac{1}{2}$ ft, has a minimum diameter at the bottom of approximately 6 ft, and weighs 45 tons. The bottom portion of the plug is filled to a depth of approximately 32 in. with 3/8-in.-dia steel shot. The middle portion is filled with a 3-in. layer of foam-glass insulation covered with fiber-glass cloth, and another 3-in. layer of foam-glass insulation covered with a sheet of 0.031-in.-thick aluminum sheeting. The upper portion of the plug is filled with high-density concrete to a depth of approximately 48 in. An additional sheet of 0.031-in.-thick stainless steel covers the aluminum sheeting and is tackwelded to it around the peripheries of a number of the sleeves that penetrate through the foam-glass insulation.

On top of the small rotating plug are mounted a number of mechanisms necessary for reactor operation. These include the platform on which the 12 control-rod drives are mounted, the superstructure for the mechanism that lifts the reactor-vessel cover, and the mechanisms for the fuel-handling holddown and gripper. To accommodate this equipment, the small plug is pierced by 17 vertical sleeves to accept the two reactor-vessel cover-lifting shafts (4.5-in. OD), the subassembly holddown shaft (6.0-in. OD), the subassembly gripper shaft (3.75-in. OD), 12 control-rod drive shafts (2.5-in. OD), and one spare nozzle (3.75-in. OD).

Except for dimensions, the freeze seal for the small plug is similar to that for the large plug (shown in Fig. 5). The upper, stainless steel ring of the blade is 82.625 in. in ID, 8.625 in. high, and 1.125 in. in wall thickness. The lower, copper ring had the same ID as the upper, stainless steel ring of the blade and was 2.0 in. high and 1.0 in. thick; there was also a 1.125-in.-high inert-gas void between these two rings.

The annular seal trough is made of 0.188-in.-thick Type 304 stainless steel plate, 84.25 in. in OD, 11 in. deep, and 3.0 in. wide. The bottom of the trough is insulated with a 0.188-in.-thick false floor. The trough is filled to a depth of about 9 in. with the same type of seal alloy as used for the large plug.

The electrical-resistance heaters, the "blade" thermocouples, and the trough thermocouples are the same type as those used for the large plug but fewer in number, totaling 80, 8, and 64, respectively. The trough thermocouples are inserted to four separate elevations (as shown in Fig. 9): 8.125 in. (level 1A), 7.50 in. (level 1B), 5.25 in. (level 2), and 2.25 in. (level 3)--all measured from the bottom of the trough.

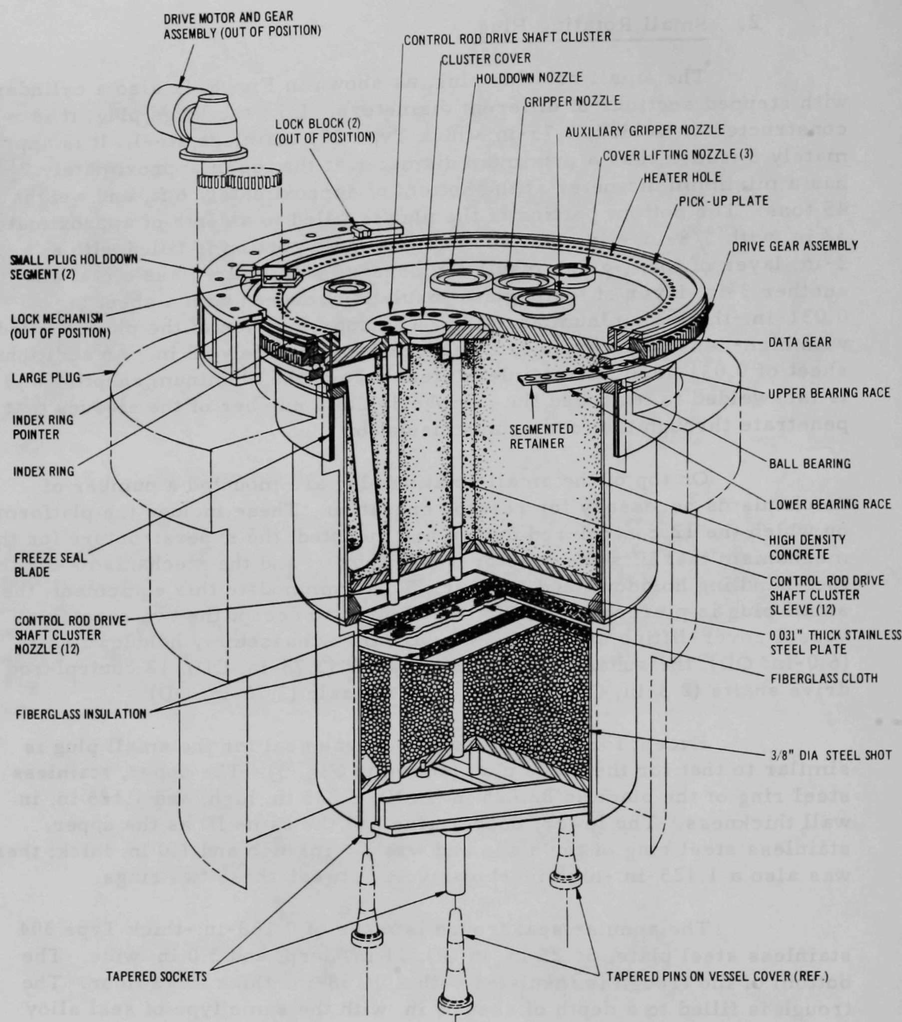


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Fig. 8. Cutaway View of Small Rotating Plug

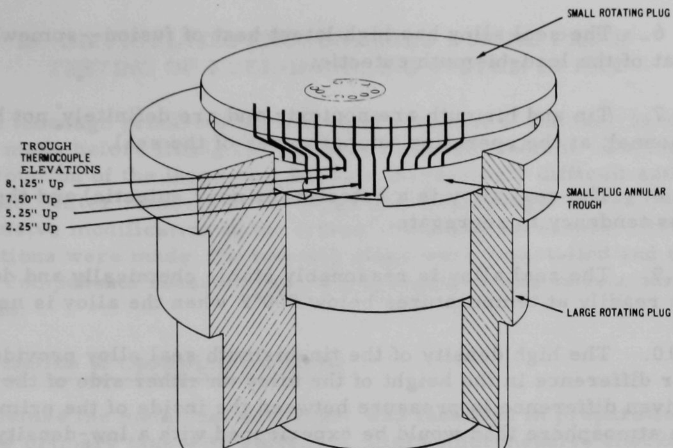


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Fig. 9. Trough Thermocouple Locations of Small Plug

## D. Choice of Seal Alloy

The seal alloy chosen for the EBR-II freeze seals was a tin-bismuth near eutectic (42 wt % tin; 58 wt % bismuth). This alloy was chosen for the following reasons:

1. It is desirable to keep the melting point below 300°F. The melting point of the selected seal alloy (281°F) was considered to be most suitable, since it was high enough to permit freezing of the seal material with the sodium in the primary tank at 700°F, yet low enough to permit melting of the seal with relatively modest heat input to the seal.

2. The seal alloy expands slightly on freezing. This was considered to be a desirable attribute at the time of the choice in 1956 or earlier. However, later it was found necessary to operate the seal in the half-molten condition to ensure a gastight seal.

3. The seal alloy is stable on solidifying and does not change dimensions with time.

4. The seal alloy has relatively high thermal conductivity--somewhat greater than that of the lead-bismuth eutectic.

5. The seal alloy has relatively high specific heat--somewhat higher than that of the lead-bismuth eutectic.

6. The seal alloy has high latent heat of fusion--somewhat higher than that of the lead-bismuth eutectic.

7. Tin and bismuth are nontoxic and are definitely not hazardous to personnel, at the operating temperatures of the seal.

8. The seal alloy is a eutectic (or near eutectic) and therefore has less tendency to segregate.

9. The seal alloy is reasonably stable chemically and does not oxidize readily at temperatures below 500°F when the alloy is not in motion.

10. The high density of the tin-bismuth seal alloy provides a smaller difference in the height of the alloy on either side of the seal blade for a given difference in pressure between the inside of the primary tank and the atmosphere than would be experienced with a low-density alloy.

The following disadvantages of the alloy have become apparent through the several years of operating experience:

1. When the surface barrier on the alloy is continuously broken, a fine black powdery dross is formed. If this dross is not removed, it eventually forms a hard crust, which causes considerable difficulty in getting the plugs to rotate.

2. The blade and trough are made of Type 304 stainless steel. The 300-series stainless steels are probably the least desirable for the containment of bismuth alloys. Chromium steels that are free of nickel, such as Types 405 and 410 stainless steel, are the most promising.

Reference 3 discusses in detail several of the metallurgical problems with the seal alloy.

In the design stages, a possible alternative to the eutectic alloy was an alloy consisting of 55 wt % bismuth and 45 wt % lead. This alternative choice was based on the following:

1. It is less aggressive to container materials.
2. It is a eutectic composition.
3. The melting point is 225°F.
4. It has a lower oxidation rate than the other tin-bismuth eutectic alloy.

However, this alloy was not chosen as it did not meet the requirement of small expansion on freezing and no dimensional change on solidification.

## II. DIFFICULTIES ENCOUNTERED DURING PROOF-TESTING OF FUEL-HANDLING SYSTEM IN 1962

A thorough proof-testing and final checkout of the fuel-handling system was made before filling the primary tank with sodium. During this period, rotation of the large plug became increasingly difficult and finally impossible. After removal of the large and small plugs, it was evident that extensive modification to the freeze seals was necessary. After these modifications were made, the rotating plugs were reinstalled and fuel-handling components reassembled. Final checkout was satisfactorily completed.

### A. Description of Operating Difficulty

Before the main heat exchanger was installed in preparation for filling the primary tank with sodium, a final comprehensive checkout of the fuel-handling system was undertaken. The checkout proceeded smoothly until the first week of July 1962, when difficulty was encountered with rotation of the large plug. Initially, an occasional "sticking" of the plug with resultant slippage of the clutch on the motor drive unit was noted. This was thought to be caused by excessive thermal expansion of the large ring gear on the plug, resulting in interference with the mating drive gear. The plug had been operating at an abnormally high temperature, as a result of several days' operation with the seals molten and with no flow of cooling air. Prior to this time, before filling of the seals, the plug had been operated primarily at room temperature. The drive mechanism was therefore loosened to increase the clearance between the gears. The unit then operated freely, and it was assumed that the cause of sticking had been corrected.

Two days later, however, sticking again occurred with similar characteristics. The drive unit was again loosened. The plug then turned, but stuck once more in another position. The drive unit was finally replaced with a manual drive, which had been used during the original installation. This permitted hand rotation of the plug, providing some "feel" of the sticking characteristics. It was found that the plug would stick in a non-systematic manner and tended to "bounce" slightly when motion was stopped by the unknown obstruction. This led to the conclusion that a flexible material might be jammed or wedged in one of the clearance spaces, and also that the interfering material might move with the plug, accounting for the change in the position (angle) at which sticking occurred. A possible source of such a flexible obstruction was a heavy-walled rubber hose, which had been inserted in the clearance slot between the plug support and the primary-tank structure. This hose had been inserted to close this clearance slot and eliminate bypass airflow in the shield-cooling system.

The hose was relatively inaccessible and could not be readily seen except through mirrors and offset viewing devices. Although the hose did not appear to have become dislodged in any way, the decision was made to remove it. The hose was eventually removed with some difficulty, but did not in any way affect the plug-sticking characteristics.

In reviewing all the factors relating to the plug sticking, we decided that the problem might be related directly to the heating of the freeze seal. No definite mechanism was postulated, but the very long period of successful operation at room temperature seemed to strengthen this possibility. Therefore, the decision was made to drain the tin-bismuth alloy to permit cooling the seal and simultaneously allow rotation of the plug, since rotation is not possible with the seal frozen. Draining of the seal required prior removal of a few lower-blade heaters to provide access to the bottom of the trough. Difficulty in removing the heaters was immediately encountered, and it was discovered that the heaters were bent at their lower extremities. Three were removed, and all were bent at approximately 2 to 4 in. from the lower end. A matching of the location of the bends with the design of the seal blade led to the conclusion that the lower ring of the blade had become displaced and that the blade had become mechanically jammed in the trough.

The alloy was drained to a depth of about 3/4 in.; then borescopes were inserted as far as possible into empty heater holes. Although visibility was extremely limited, it was confirmed that portions of the blade's lower (copper) ring had become separated from the remainder of the blade and had settled to the bottom of the trough. The need for removing the large plug to permit examination and repair was evident. Because the design of the freeze seal for the small rotating plug is similar to that for the large plug, it was decided to remove both plugs.

## B. Description of Dismantling Operations

In preparation for removal of the plugs, it was necessary to dismantle either completely or partially many of the mechanisms installed on them. The reactor-vessel cover-lifting drive mechanism and superstructure were removed; the lifting columns were left in place on the vessel cover that earlier had been deposited on a temporary support built atop the reactor vessel. The fuel-handling holddown mechanism was removed, including the drive shaft and funnel. The uppermost portion of the gripper drive mechanism was dismantled, but the lower portion and the drive shaft were left in place. The festoon cables were removed. Shear keys and holddowns for the two plugs, all wireways that might interfere with lifting of the plugs, and a substantial amount of electrical wiring were removed. Much of the permanent wiring for the freeze-seal heaters and thermocouples for the two plugs was replaced with temporary wiring to permit melting (and temperature monitoring) of the residual alloy in the seals at the time of lifting the plugs.

Because dismantling and later reassembly of the 12 control-rod drive assemblies would represent a large additional effort, consideration was given to attempting removal of the small plug with the control-rod drives attached. This required that the plug be raised vertically some 21 ft with the cover-lifting columns sliding through the plug for the entire distance, and with the control-rod drive shafts and gripper drive shaft sliding through their sleeves in the reactor-vessel cover for the first 7 ft of movement. Because of the small clearances involved, particularly between control-rod drive shafts and cover sleeves (0.015 in.), any significant tilting, lateral movement, or rotation of the plug during lifting could be expected to produce binding and serious damage. Detailed examination of possible methods of lifting eventually indicated that such a lift could be accomplished safely. Special lifting fixtures and alignment guides were fabricated and new hoist slings procured. Precision levels were mounted on the plug. Dial indicators for sensing lateral motion of the plug were installed.

After completion of all preparations, the small rotating plug was successfully removed and deposited on a newly fabricated support structure in the reactor-building basement. The large plug was removed without difficulty and placed on the operating floor.

## C. Description of Damage

Examination of the large-plug seal revealed that severe corrosion had occurred in the lower (copper) ring of the seal blade. The tin-bismuth alloy had attacked the copper most heavily in the vicinity of the heaters, where the highest temperatures had existed. At these locations, the lower ring was of minimum thickness (as shown in Fig. 5) and in numerous places had corroded through, permitting segments of the ring to fall to the bottom of the seal trough. There the segments caught on projections in the trough (probably retaining clips on the insulator cans) and prevented rotation of the plug. Damage was limited to the lower ring of the seal blade and to some insulator cans positioned within the trough. The upper (stainless steel) ring of the blade and the trough itself were undamaged.

Figure 10 is a view of the large-plug seal blade as seen from underneath. Numerous spaces are evident from which the copper segments had fallen out. A few segments in which bolts happened to be located are retained in place. The lower-blade heaters are also evident. (The one extending below the blade bottom was inadvertently pushed there during inspection of the blade.)

Figure 11 shows the large-plug seal trough after removal of the plug. The "crud" at the trough bottom consisted of undrained tin-bismuth alloy and copper. Analysis indicated that this material contained up to 8% copper, but the sound alloy (samples from the alloy drained from both troughs) contained only a few hundred ppm of copper. For comparison, Fig. 12 shows the empty trough with insulator cans and retaining clips before installation of the plug.

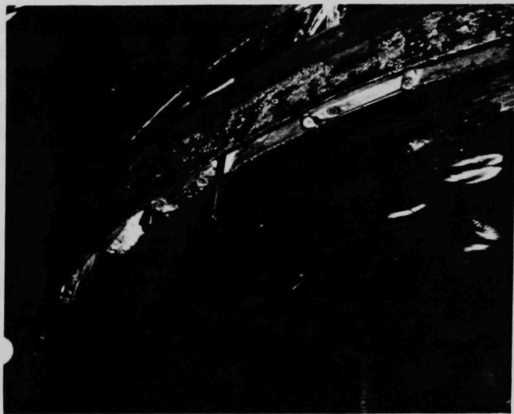

Fig. 10

Large Rotating Plug Showing Damaged Dip Ring

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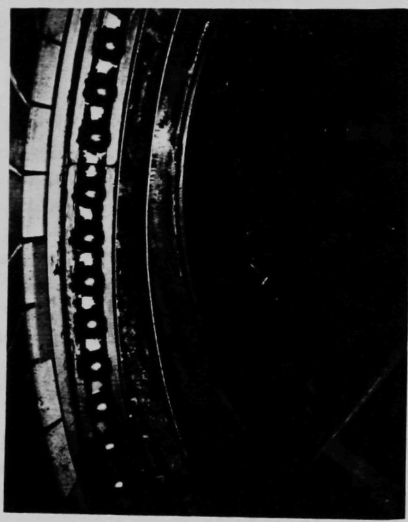

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Fig. 11. Large-rotating-plug Seal Trough after Plug Removal

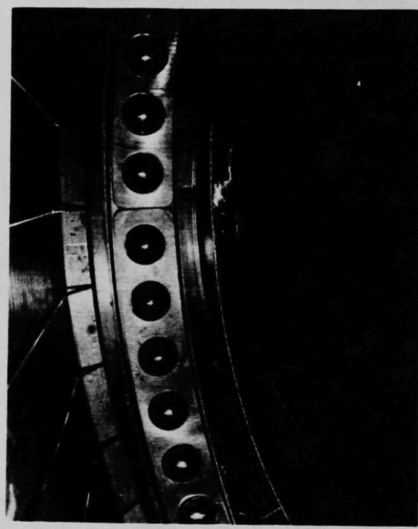

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Fig. 12. Large-rotating-plug Seal Trough before Plug Installation

No physical damage occurred to the small-plug seal, except for excessive corrosion of the lower ring of the blade. Although the maximum corrosion again occurred at the heater-hole locations, it had not progressed to the same extent as in the large-plug seal, and the copper ring was intact. Figure 13 shows the ring segments with some of the stainless steel spacers and mounting bolts. The residue in the small-plug seal trough, not pictured here, was similar to that in the large-plug trough.

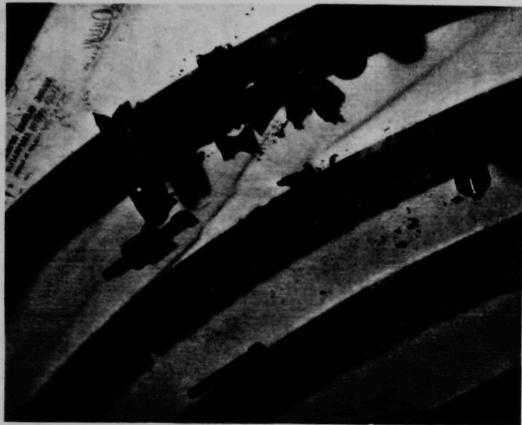

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Fig. 13. Damaged Segments of Lower Copper Ring of Small-plug Blade

## D. Modifications to Freeze Seals

After the extent of damage to the freeze seals was determined, the following repairs and modifications were made:

(1) Blade and trough modifications

(2) Provisions for access to the seals

(3) Gas seal and nitrogen purge

(4) Revisions to the air-cooling system

(5) Revised temperature-control system.

Figures 14-16 show the freeze seals following these modifications.

### 1. Blade and Trough Modifications

The freeze-seal blades for both plugs originally consisted of an upper ring of Type 304 stainless steel and a lower ring, integral with the upper ring, of copper, with an inert-gas void between the rings. Because of corrosive attack by the tin-bismuth eutectic alloy on the copper lower rings, these rings were removed and replaced by a Type 304 stainless steel ring. This lower ring is a bolted and welded extension to the upper, stainless steel ring and is 3.25 in. deep. To compensate for the lower thermal conductivity of the stainless steel lower ring, the active (heated) length of each of the upper electrical-resistance heaters was extended downward into the lower ring; the active length of the upper heaters was increased from 3.3 to 5.5 in., and the active length of the lower heaters was increased from 1.75 to 2.50 in. (see Fig. 17).

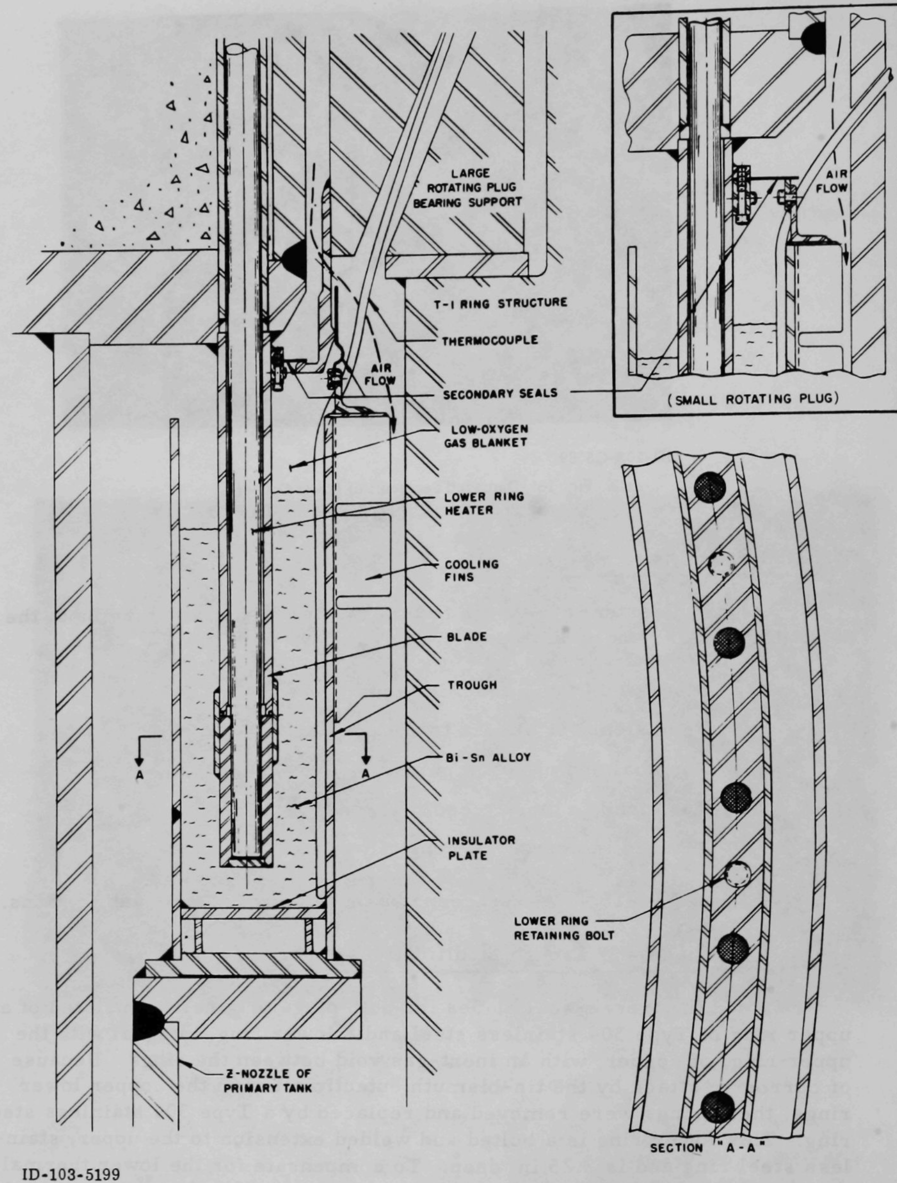


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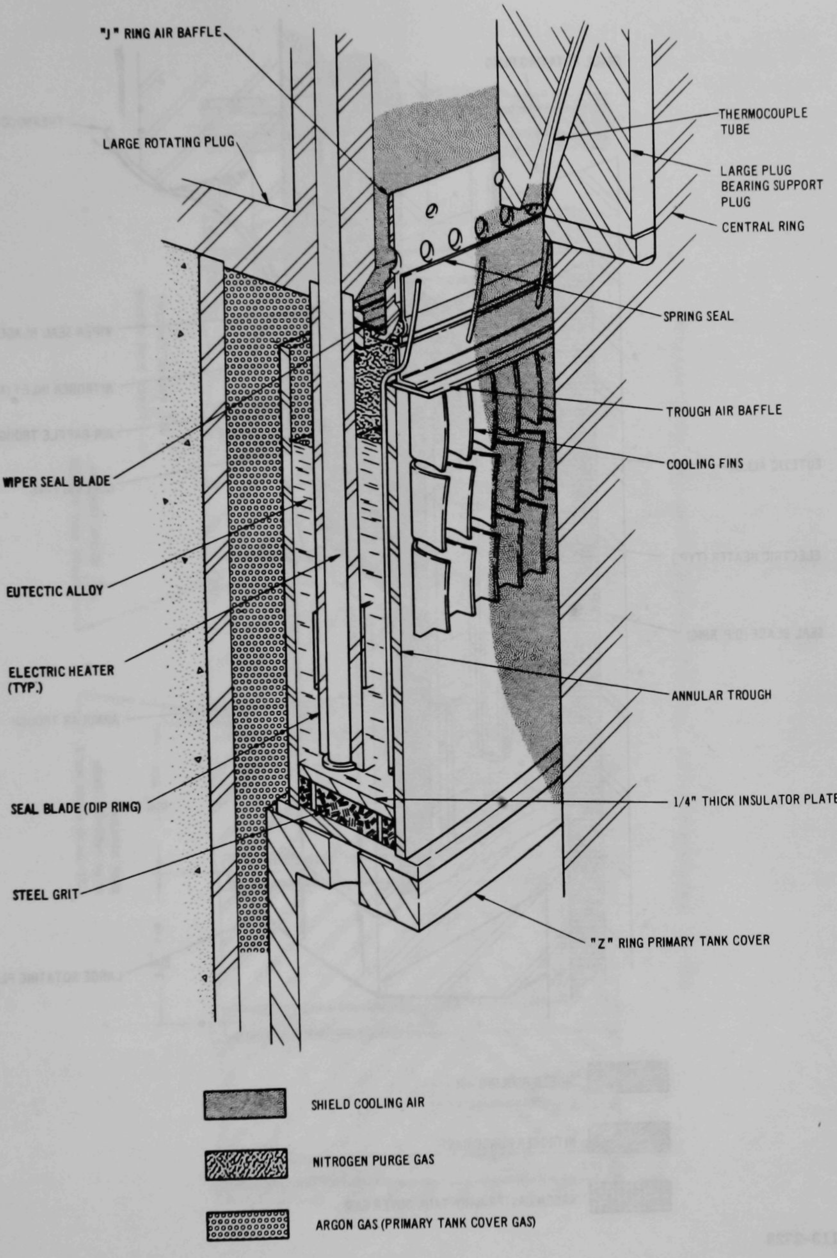
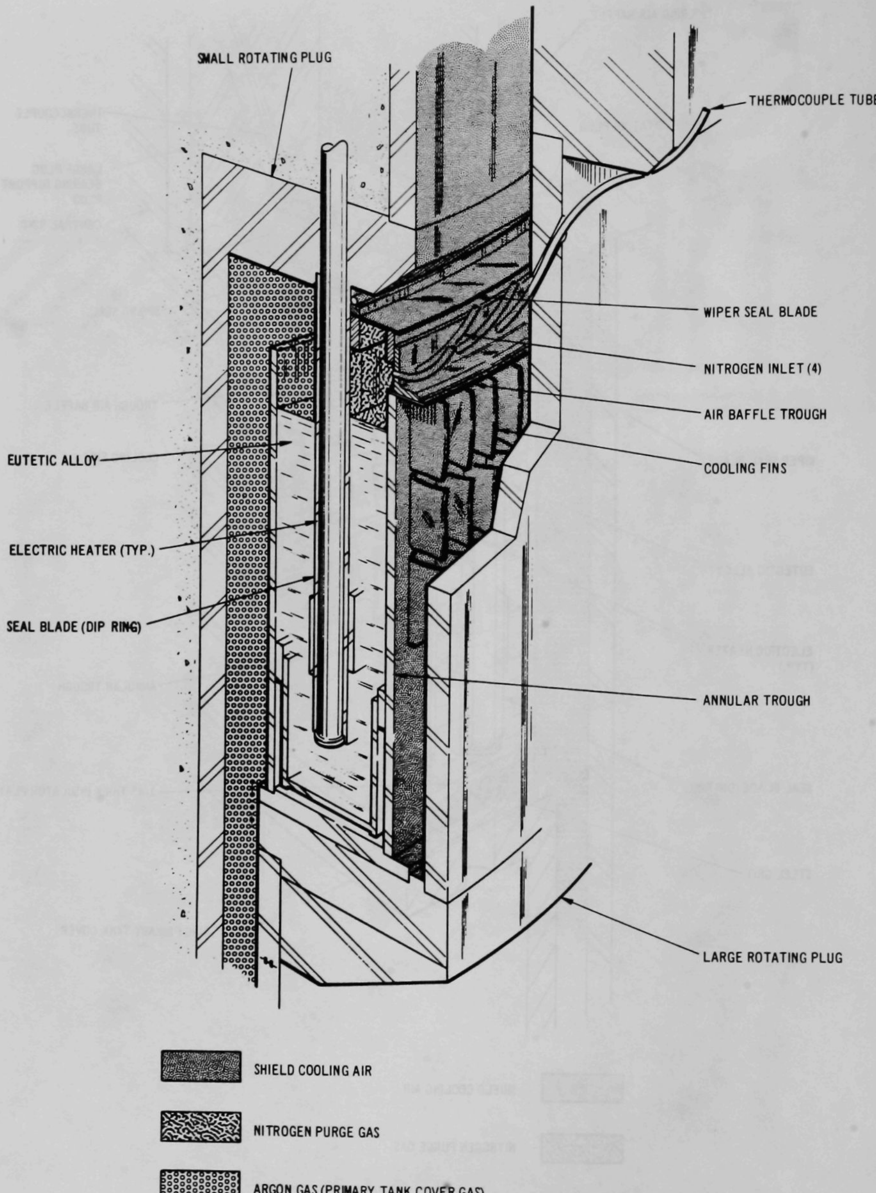
Fig. 14. Cross Section of Large- and Small-rotating-plug Freeze Seals after Modification



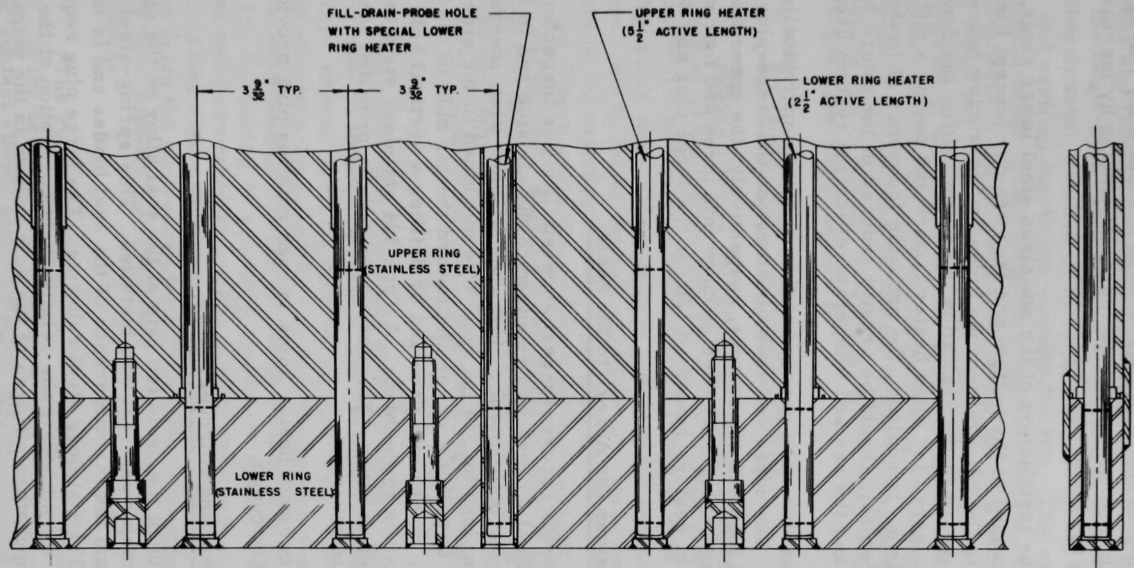

113-2722

Fig. 15. Isometric View of Large-rotating-plug Freeze Seal after Modification




113-2728

Fig. 16. Isometric View of Small-rotating-plug Freeze Seal after Modification




112-2838

Fig. 17. Arrangement of Upper and Lower Blade Rings and Heaters after Modification

The original insulator cans were removed from the bottom of the large-rotating-plug seal trough and were replaced with an insulator plate. The insulator plate provides a backup weld to prevent alloy leakage from the seal trough, and eliminates a possible source of binding by increasing the clearance between the blade and the trough.

With the installation of the stainless steel lower rings, all heater holes are capped at the bottom and thus are dry (except for five in each seal located in the fill-drain-probe holes or the window holes). Heaters are no longer immersed in the seal alloy, thus eliminating the danger of their becoming "soldered in" after heater failure and posing a difficult replacement problem. In addition, the probable frequency of heater failure, or need for replacement, should be greatly reduced in the future by the lower heat fluxes and the revised temperature-control system used.

The heaters were grouped at this time into individually controllable sectors. The upper and lower heaters for the large-plug seal were grouped into four and six sectors, respectively; the upper and lower heaters for the small-plug seal were grouped into three and four sectors. The total number of heaters remained 120 for the large plug and 80 for the small plug.

### 2. Provisions for Access to the Seals

To provide for freeze-seal accessibility (for inspection and sampling of the alloy), access was required to the air side and to the argon side of the blades for both rotating plugs. A "window" slot, measuring approximately 5 in. long by 3/4 in. wide, was machined in the side of a "dry" heater hole to provide an opening toward the air side of the trough. On the argon side, access was provided by drilling a vertical hole through the plug body, adjacent to the blade. A Type 304 stainless steel tube was inserted and welded in place. This inspection hole is provided with a gasketed Pyrex window.

The six "wet" heater holes in each rotating plug provide access to the bottom of the trough.

### 3. Gas Seal and Nitrogen Purge

To reduce the oxidation rate of the seal alloy on the air side of the troughs, an annular gas seal was installed. This spring-steel gas seal was mounted around the circumference of the seal blades and is in compression with a Type 304 stainless steel rub-ring. The large plug required an additional seal to accommodate the relative vertical motion of the blade and trough during temperature changes of the bulk sodium in the primary tank. To protect the alloy from oxidation, the gas seals were purged with argon (later nitrogen) when the seal alloy was in the full-molten condition. The argon blanket for the bulk sodium communicates to the inner side of the blades, protecting this seal-alloy surface from oxidation.

The gas seals were difficult to design because of the necessity for adapting them to the existing equipment, with the attendant space limitations and fabrication and assembly problems. This was particularly true of the large-plug seal. Here the seal had to accommodate two types of relative motion: rotation of the plug (or seal blade) with respect to the trough, and vertical movement between the two. The vertical movement is large, on the order of half an inch; it happens because the trough is mounted on the Z-nozzle of the primary tank, while the plug is mounted on the tank support structure. When the primary tank is heated to 700°F for normal power operation, the center portion of the primary-tank cover (to which the Z-nozzle is attached) undergoes downward movement with respect to the support structure; this movement is due to lengthening of the primary-tank hangers and to bowing, or dishing, of the cover because of the normal temperature differential across it.

## 4. Revisions to the Air Cooling System

During reactor operation, the alloy is maintained frozen at the top but molten at the bottom with the aid of biological-shield cooling air. The shield-cooling flow is required at all times to cool the biological shielding, since the primary tank is continuously transferring heat to this structure. Air is drawn through openings in various nozzles in the top structure of the primary tank and through air inlets in the large and small plugs. The freeze seals are cooled by airflow past the outer side of the troughs; cooling fins, attached to the upper portion of the troughs, maintain a vertical temperature differential between the top and bottom of the seal alloy. Six air ducts in the small plug direct the airflow past the small-plug trough; 12 air ducts in the large plug direct the airflow past the large-plug trough.

Several revisions were made in the air-cooling system within the rotating plugs to improve control of the vertical temperature gradient in the seal alloy. Filters were installed at all air inlets on both plugs. Manually operated dampers were installed in each of the small-plug air ducts. Manual dampers were installed in the two large-plug air ducts that formerly had none. The remaining 10 air ducts contained manual dampers. These dampers were reworked to provide a "closed" position and to provide a continuous, rather than a three-step, adjustment. The rubber hose that was removed from the clearance slot between the large-plug support and the primary-tank support structure (see p. 21) was replaced with a permanent steel closure.

The rotating-plug support-bearing seal on each rotating plug was revised. In the new design an almost gastight barrier is provided by a positive-contact sliding seal employing a resilient ring of Teflon-impregnated-asbestos gasket material in compression against an annular ring of spring steel. This arrangement eliminates the airflow through the bearings that formerly short-circuited a portion of the rotating-plug cooling-airflow paths, and also prevents any accumulation of airborne dust in the bearing grease.

### 5. Revised Temperature-control System

A revised seal-alloy temperature-control system was designed and installed to ensure operation of the freeze seals at the minimum practicable temperature and with a temperature distribution as uniform as possible. Formerly, the upper heaters were not energized with the seals in the full-molten condition; heating was accomplished by energizing the lower heaters only. On-off control was used, all lower heaters being energized or deenergized in unison. Six and four thermocouples, respectively, in the large- and small-plug seal troughs were used for control-temperature sensing. A high sensing from any one thermocouple deenergized the heaters; a low sensing from any one energized them.

The new system uses both upper and lower heaters. The upper heaters are constantly energized at low power, and the power level may be varied from sector to sector around the seals. On-off control of the lower heaters is again used, but by sector. The heaters are grouped electrically into sectors (see p. 30), each sector being controlled individually. Six and four thermocouples, respectively, in the large- and small-plug seal blades, one per sector, are used for control-temperature sensing. During plug rotation, each control thermocouple bears a constant spatial relationship to the sector of heaters, which it controls irrespective of plug position. This improved control system, together with the revised heater arrangement, permits maintenance of a more nearly uniform temperature around the seal periphery at the molten alloy surface. This uniformity, in turn, results in a lower maximum (local) alloy temperature consistent with assurance that the alloy is fully molten. The seals can now be operated with a maximum temperature of less than 400°F.

## E. Reassembly of Fuel-handling Components

After completion of the above-listed modifications to the rotating plugs and the freeze seals, the plugs were reinstalled without difficulty. All the fuel-transfer mechanisms on the rotating plugs were reassembled. These included the mechanism for lifting the reactor-vessel cover, the fuel gripper and holddown mechanisms, the drive motors for rotating the shield plugs, parts of the festoon cable arrangement, and many electrical installations.

Again, a thorough proof-testing and final checkout of the fuel-handling system were made to check the correctness of the electrical installations and all mechanical adjustments. The primary tank was filled with 88,000 gal of sodium and brought to temperature. Wet criticality of the reactor was achieved in November 1963.

## III. SEAL-HEATER REPLACEMENT

During fuel handling in May 1965, seven blade heaters failed; five of these failed heaters were from the small-plug blade, and two from the large-plug blade. The heater in hole No. 164 in the small plug was ruptured approximately 3/8 in. up from the bottom on the side; this rupture was 1/4 in. wide and approximately 1 in. long; on the opposite side was a second rupture 1/8 in. in diameter. The Type 304 stainless steel sheath was eroded away, exposing the electrical MI insulation above the ruptures for approximately 3/8 in. The eroded part was approximately 3/4 in. long.

Another failure involved a wet-type heater in small-plug hole No. 148; the heater showed evidence of erosion approximately $1\frac{1}{4}$ in. up from the bottom. The exact amount of erosion was difficult to determine. By micrometer, the upper part of the heater measured 0.495 in., which is design diameter; the section considered to be eroded had a diameter of 0.473 in. The metal surface of the latter section was not smooth, but was pitted and irregular as if eroded.

Three other heaters in the small plug failed; the heating element on each had opened. Although these were dry-type heaters, they were found wetted as shown in Fig. 18. The tabulation below lists the condition of all the heaters replaced during this problem interval:

| Heater No. | Type | Location | Condition |
|---|---|---|---|
| 154 | Dry | Small plug | Wet and open |
| 166 | Dry | Small plug | Wet and open |
| 178 | Dry | Small plug | Wet and open |
| 164 | Wet | Small plug | Ruptured |
| 148 | Wet | Small plug | Open |
| 310 | Dry | Large plug | Open and dry |
| 319 | Dry flexible | Large plug | Open and dry |

In the investigation of these failures, it was taken into consideration the Type 304 stainless steel of the heater sheaths could be expected to corrode at appreciable rates at 660°F and above. The elements that particularly contribute to the increased corrosion rates are the tin content of the tin-bismuth alloy and the nickel of the Type 304 stainless steel.

An extensive effort was made to establish the temperature pattern of the seals, both during heating and at the temperature level attained shortly before rotation. However, the temperature indicated by the thermocouples did not necessarily represent the true temperature of the tin-bismuth alloy, usually indicating a much lower temperature than the actual temperature of the alloy. It was later learned that dross accumulated around the thermocouples, thermally insulating them from the alloy.

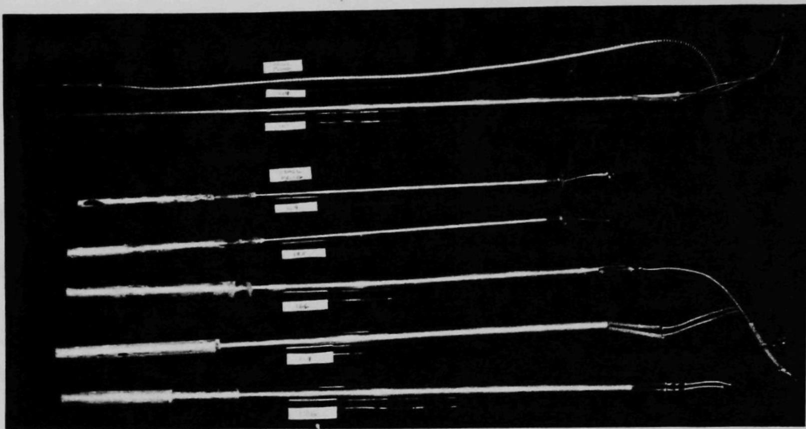


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Fig. 18. Failed Blade Heaters

Examination of the failed heaters that showed corrosion indicated that they had been in contact with the molten tin-bismuth alloy at very high temperatures. The recommendation was therefore made to replace the nickel-bearing Type 304 stainless steel of the heater sheaths by a stainless steel of the 400 series. The most suitable of these steels could not be predicted offhand, but was determined by a research approach.

Type 405 ferritic stainless steel was found to be the most suitable material. In January and February 1966, the 120 large-plug blade heaters were removed and replaced with heaters clad with Type 405 stainless steel. One heater, No. 315, broke where the flexible conduit is joined to the heater. A new heater was installed on top of the stuck heater. (Four heaters have been installed in this manner where a failed heater could not be removed.)

At this same time, 77 heaters in the small plug were successfully removed and replaced with new heaters clad with Type 405 stainless steel. Three heaters in positions No. 121, 153, and 169 were severed approximately 6 in. from the bottom, leaving the lower portion in the plug blade. By a combination of drilling and reaming, most of the remaining portion of each heater was removed. The remaining three heaters were then installed.

When the heaters were removed from the large-plug blade, it was found that all the dry holes were dry; i.e., no seal alloy was present. The opposite situation was found when the heaters were removed from the dry holes in the small-plug blade; all the dry holes were wetted by varying amounts of alloy. In general, the dry heaters were wetted for a length of 9 in., measuring from the bottom. The wetted length was silvery in color when the heater was removed. Very little, if any, indication of oxidation was evident. This wetting is attributed to small cracks in the upper skirt-weld on the inner side of the blade. This failure is of a minor nature and will be corrected only if the small plug is removed for a different purpose.

## IV. ROTATIONAL DIFFICULTIES CAUSED BY DROSS AND CRUST

### A. Initial Difficulties and Diagnoses

During 1964, seal melting took progressively longer and the power input to the heaters was increased. This did not reduce the melting time, and samples of the eutectic metal were taken. A dry, black, powdery oxide was found on top of the seal alloy on the nitrogen side of the seal. The presence of some sodium in both the black oxide and the metal showed that sodium was diffusing around the blade and was being oxidized on the surface of the seal alloy. A "vacuum cleaning" technique was used to remove as much of the black oxide as possible. This was accomplished by connecting a 1/2-in.-dia tube to a vacuum cleaner and inserting the tube in a window hole down to the liquid level. With a thermocouple inserted in the window hole, it was shown that the seal temperature was approximately 150°F hotter than the level 1A and 1B thermocouples were reading. The trough thermocouple wells were coated with dross (the dry, black, powdery oxide), giving very poor heat transfer to the thermocouples and causing the lower temperature reading.

During preparations for unrestricted fuel handling in late June and July 1965, it became difficult to obtain indication of satisfactory temperature distributions in the seal troughs. Furthermore, difficulty was experienced in attempting to initiate the rotation of plugs by motor drive. It was necessary to assist the drive manually in order to loosen the large plug and obtain free rotation.

Several causes for the plug rotational difficulties were postulated. These are described in detail in the following paragraphs.

#### 1. Abnormal Temperature Distributions in Plugs and Troughs (effects of faulty heat control or improper cooling-airflow)

Plug-sticking problems encountered in 1963 were attributed to faulty temperature control resulting from poor performance of control-system components. The heater-control system had been replaced in January 1964, after which temperature distributions were improved in the seal troughs, but only after long "soaking" times (i.e., period between energizing of heaters and attainment of proper temperatures for rotation).

2. Segregation of Alloy Components

Laboratory studies have shown that tin and bismuth can segregate during solidification of the alloy.[4] The "half-molten" condition of the EBR-II seal troughs, where the upper portion of the alloy is maintained frozen while the lower portion remains molten, may promote segregation at the interface between the frozen and molten zones. A network of segregated bismuth crystals bridging the space between the blade and the trough wall was suggested as a possible cause of interference with rotation. These crystals would probably redissolve slowly in molten alloy, accounting for the long soaking times required to achieve plug rotation.

Chemical analyses of the many alloy samples that have been taken from the seal troughs have not given evidence of gross alloy segregation. However, because of the difficulties involved in obtaining representative samples, these analyses do not indicate unequivocally whether segregation is occurring.

Probing through the "window slot" of each blade consistently indicated the presence of a "mushy" layer below the surface of the molten alloy. However, because of stringently limited access, it was not possible to determine with assurance whether this layer exists around the blade periphery or only in the vicinity of the window hole.

If an extensive layer were known to exist, it would support the segregation theory. However, such a layer could also be accounted for as deposits of metal and oxides (see 3 and 4 below).

3. Oxide Accumulation in the Seal-trough Outer Annulus

Significant oxidation of the eutectic is known to have occurred in the outer annulus because of (1) high partial pressures of oxygen in the nitrogen purge gas, and (2) probable high temperatures of the alloy during molten operation with faulty heater control or with high temperature-control setpoints during attempts to establish proper temperature distributions.

The oxygen content of the purge gas results from air leakage past the mechanical seal over the trough annulus (see Table I).

4. Sodium or Sodium Oxide Deposition in the Plug Annuli

It has been postulated that plug sticking could be due to sodium or sodium oxide deposits in the annulus between the large rotating plug and the Z-ring of the primary-tank cover, and in the annulus between the large and small rotating plugs. This could account wholly for the observed sticking or, taken together with a seal-trough problem, could contribute to the sticking.

TABLE I. Oxygen Concentrations in the Purge Nitrogen of the Large-rotating-plug Seal Trough

| | |
|---|---|
| Seals: | Molten condition |
| Primary-sodium temperature: | 271°F |
| Shield-cooling static pressure: | -2.1 in. $H_2O$ |
| Data taken: | August 5, 1964 |

| Nitrogen Flow, cfm | Oxygen, vol % | Nitrogen Flow, cfm | Oxygen, vol % |
|---|---|---|---|
| 5.0 | 5.0 | 4.5 | 7.4 |
| 4.0 | 8.6 | 4.0 | 7.5 |
| 4.5 | 6.9 | 5.0 | 9.6 |
| 3.75 | 10.0 | 5.0 | 6.4 |
| 5.0 | 5.4 | | |

Removal of the EBR-II fuel-transfer arm in February 1966 gave an opportunity to use the transfer-arm nozzle of the primary-tank cover for inspection. A periscope and a light source were used in the open transfer-arm nozzle to inspect the annuli between the large and small rotating plugs and between the large rotating plug and the primary-tank cover. The purpose was to determine whether the sticking problem with the rotating plugs might be caused by deposition of sodium or sodium oxide in these annuli.

Because of the limitation on length of the viewing device imposed by the dimensions of the transfer-arm nozzle, only a limited arc (a few degrees) of the small-plug annulus could be viewed. However, points on an arc of about 60° of the large-plug annulus, in the vicinity of the transfer-arm nozzle, were viewed. The small-plug annulus at the point viewed appeared to be free of deposits. Deposits were observed near the bottom of the large-plug annulus at several locations viewed. These deposits appeared to be collections of "globules." It is surmised that these were droplets of sodium from "refluxing" of sodium vapors in the annulus. There was no evidence of annulus blockage at any location viewed. However, because of the limited area and the difficulty in providing a sufficiently strong light source to permit clear viewing in the upper part of the annulus, we could not positively ascertain that obstructions did not exist.

To provide additional information concerning the possibility of sodium deposition in the annuli, temperatures were measured above the step in the large-plug annulus. Measured temperatures were above the melting point of sodium, even though the bulk-sodium temperature in the primary tank had been lowered to 280°F.

5. Mechanical Interference

There always exists the possibility of interference and binding of the gas seals above the air side of the troughs. These gas seals are inaccessible to inspection. A deteriorated condition of one or more of the supporting bearings may exist. Also, the air seal for the bearings may cause interference.

## B. Analyses of Seal Alloy

Because of the rotational difficulties, many samples of the seal-trough tin-bismuth alloy have been chemically analyzed. Of most significance to date is the finding of substantial quantities of metallic oxides in the outer annuli of the troughs. These annuli are accessible for observation and sampling only through the "window slots," one each in the large- and small-plug blades. The "window slot" is a heater hole having a slot approximately 3/4 in. wide extending from the elevation of the trough top to about 3 in. below the alloy surface. Probing with a wire through the window slot of each dip ring revealed the presence of spongy or crusty layers or deposits in the outer trough annulus, mostly submerged 1 or 2 in. below the surface of the molten alloy.

Samples of these deposits were taken in a syringe of 3/8-in.-OD tubing having a plunger. The deposits contained molten metal, black powdery oxide, and porous black clinkers or nodules. Chemical analysis of the oxide portions, especially nodules, of some samples revealed that they were predominantly oxides of bismuth, tin, and sodium. Sodium, as sodium oxide, accounted for 12.5 wt % of one sample. Two other samples showed sodium content corresponding to around 10 wt % sodium oxide, and the remaining two oxide samples of the five analyzed contained sodium equivalent to 3 or 4 wt % oxide. The iron content of the oxide was very low (less than 0.25%).

The presence of oxide deposits (or mixtures of metal and oxide) in the annuli can plausibly account for plug sticking and also for apparent poor temperature distribution in the troughs. As for the latter, it appears that the oxides blanket some of the upper-level thermocouples, causing low indicated temperatures by interfering with heat transfer from the alloy to the thermocouples. This has been substantiated by probing through the window slot at locations where the thermocouple readings appear too low, thereby obtaining increased temperature readings, apparently by disturbing the oxide deposits and bringing molten alloy into contact with the thermocouples.

Analysis of many metal samples from the troughs have provided no evidence of gross segregation of tin and bismuth. However, the sodium content of these samples has ranged between 1500 and about 2000 ppm (as sodium). It is possible that sodium aerosol or vapor in the primary argon dissolves in the alloy, diffuses through the body of the alloy, and reacts with oxygen in the nitrogen purge gas at the surface of the alloy in the outer annulus. The apparent submergence of the oxide deposits may result from a "plowing" action of the dip ring and the adherent deposits during rotation.

The probability of accumulation of a significant amount of sodium in the rotating-plug seal troughs is extremely small, and is below what may be accepted as a reasonable engineering risk. Operating experience at ANL with other equipment having a long, narrow, vertical passage with a large temperature differential (conditions characteristic of the rotating plugs) has contributed to this belief.

## C. Additional Access to Seal Troughs

Improved access to the outer annulus of the small-plug trough was provided in August 1966 by drilling out a pickup-plate holddown bolt hole situated between heater positions No. 118 and 119. Access to the outer annulus of the large trough was improved in September 1966 by enlarging and modifying window-heater position No. 243.

The first operation performed through the new access hole was vacuum cleaning to remove as much drossy or oxide-like material as possible from the surface of the alloy. Approximately 26 lb of material was removed from the small-plug trough by this method, and approximately 50 lb from the large-plug trough.

After the vacuum cleaning, exploratory probing of the alloy in the outer annuli of the troughs disclosed the presence of moderately compacted deposits of oxide-like material extending about 8 in. down in the trough and, except for a few discontinuities, apparently extending around the trough circumference. This material could be removed by "coring" with a 1/2-in.-dia tube. Accordingly, the method was used to remove as much material as practicable.

Following the cleaning operations, the alloy levels in the troughs were measured to be 8 in. in the small-plug trough and $6\frac{3}{4}$ in. in the large-plug trough. New alloy had to be added to restore the specified levels for operation, which are 9 and $8\frac{1}{4}$ in., respectively.

The material removed contained an indeterminate amount of metallic alloy--both as the unoxidized metallic component of the "dross" and as small bits of alloy removed with the oxide-like material during cleaning operations. Therefore, the weights quoted above should not be construed as actual oxides of the alloy components, even though the bulk of the material had oxide-like characteristics.

Two selected samples of nodular oxide-like material were analyzed chemically for bismuth and sodium content. Results were as follows:

| | Sample No. 1 | Sample No. 2 |
|---|---|---|
| | "Oxide" pieces selected from core samples of compacted material, showing more light-colored material than Sample No. 2. | Gray compacted "oxide" from core samples of compacted material. |
| Bi | 42.8 wt % | 42.3 wt % |
| Na | 5.5 wt % | 4.5 wt % |

The sodium oxide ($Na_2O$) content of samples 1 and 2, equivalent to the analyzed sodium values, were 7.5 and 6.1 wt %, respectively. These were comparable to the sodium oxide contents of previous samples.[5,6]

Some pieces of initially gray oxide in the compacted material removed from the troughs by "coring" turned white after a few hours of exposure to air. This may reflect a sodium content considerably greater than those tabulated above, which are more representative of the composite material.

The bismuth content of these samples was lower than the content of the seal alloy (which is 58 wt % bismuth), because of the presence of significant amounts of sodium, and probably also because of preferential oxidation of tin, resulting in a larger percentage of tin in the "oxide" material than in the alloy.

Further work is required to define the effects of sodium upon the properties of the alloy and its oxidation products.

## D. Removal of Dross

When the coring was completed, a large quantity of oxide remained in the seal alloy and had to be removed, though a removal method was not known. Temperature profiles of the seal alloy taken through the new access holes showed that the trough thermocouples were indicating low temperatures. Oxide deposition appeared to be insulating the thermocouples from the alloy temperature, and an attempt was made to brush off the oxide with a wire brush. That effort was partially successful, and some of the temperatures began to increase and to indicate more representatively. More important, though, was the discovery that the oxide adhered to the wire brush when the brush was removed from the alloy. This "wire-brushing" technique simply involves inserting a round steel-bristled brush, about 3/4 in. in diameter, into the trough and rotating and oscillating it in the molten alloy. The oxide-like material is worked into the bristles and largely remains there when the brush is withdrawn through the access hole. This material can then be tapped out of the brush into a container.

Cleaning is accomplished by rotating the plug in 0.5° increments, inserting and removing the brush at least once at each increment, and cleaning the dross from the brush. Although crude, this method has proved effective. The coring and brushing techniques have effectively broken up the compacted material in the troughs and have removed a substantial portion of it. However, it is not known how much material remains on the alloy surface or is dispersed in the upper portion of the alloy.

Approximately 68 lb of material was removed from the small-plug trough by the coring and brushing operations; about the same amount was removed from the large-plug trough.

Improved vacuum-cleaning equipment, incorporating a large mechanical vacuum pump, was assembled for trial use, and an alloy-melting and -charging apparatus was fabricated and tested for adding makeup alloy to the seal troughs. Also, condenser-tube-cleaning brushes were procured for use in further trough-cleaning operations. These brushes are longer than those used in September 1966 and entrap more oxide material.

The two days of vacuum cleaning with the new equipment were unproductive in removing oxide material. Borescope examination of the alloy surface showed little black oxide material. However, the brush technique continued to recover some oxide-like material from the trough wall, the blade surface, and the body of the alloy, even though the amount of alloy removed with the oxide was greater than in previous cleaning operations (presumably because of the lesser amount of oxide in the troughs after the extensive cleaning in September). The brush-cleaning operation was continued until a point of diminishing returns was reached in which the amount of molten alloy removed by the brush considerably exceeded the amount of oxide material. The material removed during the later stages of the cleaning appeared to be well over 50% metal (not including the unoxidized metallic component of the oxide).

About 32 lb of material was removed from the small-plug trough, lowering the alloy level from 8 to $7\frac{3}{4}$ in. From the large-plug trough, 130 lb of material was removed, lowering the alloy level from $6\frac{3}{4}$ to $5\frac{3}{4}$ in.

A borescope was used to inspect each trough through the new access holes at several points around the circumference. The stainless steel trough walls, thermocouple wells, and dip-ring surfaces appeared to be in good condition. They had a grayish "temper film" color. There was no evidence of gross corrosive attack.

The level in the small-plug trough was increased to 9 in. by adding 127 lb of new alloy. Increasing the level in the large-plug trough to $8\frac{3}{8}$ in. required the addition of 350 lb of new alloy. Subsequent checks of alloy levels in the inner annuli (primary argon sides) showed that the level in the small-plug trough was $8\frac{3}{4}$ in. and the level in the large-plug trough was $8\frac{1}{8}$ in.

E. Alloy Composition after Cleaning

Samples of alloy were taken from the inner and outer annuli of both seal troughs in October 1966, before the last cleaning operations and the addition of new makeup alloy.

Sample descriptions and available analytical results are tabulated below:

| Sample Description | Constituent Bi wt % | Na ppm | Fe ppm |
|---|---|---|---|
| Large Plug | | | |
| (1) Alloy from large-plug (LP) trough outer annulus, taken 6.5 in. above trough bottom | 59.3 | 1500 | 46 |
| (2) Alloy from LP trough outer annulus, taken near 2 in. above trough bottom | 59.0 | 1750 | 30 |
| (3) Alloy from LP trough inner annulus, taken 6.5 in. above bottom of trough | 59.0 | 1800 | 60 |
| (4) Alloy from LP trough inner annulus, taken 2 in. above bottom of trough* | 58.4 | 2000 | 64 |
| Small Plug | | | |
| (1) Alloy from small-plug (SP) trough outer annulus, taken 7 in. above trough bottom | 57.8 | 900 | 26 |
| (2) Alloy from SP trough outer annulus, taken 2 in. above trough bottom | 57.6 | 800 | 23 |
| (3) Alloy from SP trough inner annulus, taken 6 in. above bottom of trough | 57.0 | 900 | 23 |

The foregoing analyses for bismuth content indicate that the alloy remaining in the trough after extensive cleaning operations was still close to the nominal eutectic composition (58 wt % bismuth; 42 wt % tin). Similar analyses of samples taken in May 1966 had previously confirmed the eutectic composition of the alloy in the trough.

## V. REMOVAL OF NITROGEN PURGE

To reduce oxidation of the seal alloy, a nitrogen-purge system was used for several years. The purge was used on the outside of each trough to protect the alloy during the full-molten operating mode and during cooling down to the half-molten mode.

Originally, argon gas was used for this purging function; however, nitrogen was substituted in September 1963, because a significant cost reduction could be attained. So much argon gas was used for purging the

*Sample could not be taken near bottom of inner annulus because of configuration of trough and access hole.

rotating-plug seals that the cost was becoming excessive. The liquid argon was procured in portable containers which hold liquified gas equivalent to approximately 1900 cu ft of gas at standard conditions. The use of nitrogen, stored in a bulk-storage tank, provided not only an impressive cost reduction (nitrogen costs one-fifth as much as argon), but also made possible bulk deliveries, thus eliminating the receiving, storage, handling, and return of large numbers of portable containers. The use of nitrogen did not alter the ineffectiveness of the purge.

The four nitrogen inlets on the small plug and the six nitrogen outlets on the large plug were connected in series to individual rotameters located on the console for each plug purge. The console for the large plug was mounted on the storage-basket superstructure. The console for the small plug was mounted on the large plug. A total-flow rotameter for each plug provided a total flow reading to both plug consoles. Total flow to the large plug was 210 to 240 cfh (35 to 40 cfh per inlet); flow to the small plug was 120 to 150 cfh (30 to 35 cfh per inlet). Before the start of full-molten operations, the gas atmosphere above the seal alloy on the air side of both troughs was purged continuously with nitrogen approximately 30 to 40 cfh for each outlet. This provided as low an oxygen concentration in the nitrogen cover gas as possible. While the fuel alloy went from the full-molten to the half-molten mode, the purge was continued until the level 1A thermocouples, located 2 in. from the top of both troughs, read less than 280°F. At this temperature, the eutectic alloy is frozen in the top area and oxidation should no longer occur.

The nitrogen-purge system did not reduce the oxidation of the surface of the alloy. The in-leakage of shield-cooling air, although considerably reduced by the two seals on the large plug and the seal on the small plug, contaminates the purge gas. The nitrogen purge composition for the large plug is shown in Table I.

Because of the seal alloy oxidized, even with a nitrogen purge to the seals (the oxygen content of the gas space is in excess of 5% during the purge), the nitrogen purge to both seals was discontinued. First, the nitrogen purge to the small plug was discontinued in May 1967. After the small-plug freeze seal was observed for one year with no deleterious effects, the nitrogen purge to the large-plug freeze seal was also discontinued. Since removal of the nitrogen purge, no increase in the rate of dross formation has been observed.

## VI. RECENT OPERATING EXPERIENCE

### A. Time Savings

From October 1966 through May 1969, the large- and small-plug freeze seals have undergone numerous cycles of fuel handling and reactor operation. Each cycle involves transition from the half-molten condition to the full-molten condition, then back to the half-molten condition. During the period mentioned, the large and small plugs have been in the full-molten mode for approximately one-sixth of the total time.

Presently, it takes approximately 2 hr to go from the half-molten condition to the full-molten condition required for plug rotation. Before drilling of access holes and brush cleaning of the seals, as long as 52 hr was required to melt the seals for fuel handling. Thus, the improvements to the rotating seals have netted a 50-hr saving per cycle in going from the half-molten condition to the full-molten condition. Since the number of cycles has been quite large, this saving of time has contributed to an increased plant factor.

## B. Inspection and Cleaning

The responsible systems engineer contacts the EBR-II Operations Manager or the Assistant Operations Manager whenever the large- and small-plug seals are in the full-molten condition.

As quickly as fuel-handling conditions permit, both plugs are rotated 360°, then back 360° to the operate position. The fuel-handling crews carefully observe the movement of both rotating plugs for any signs of stickiness or other abnormal conditions, such as slower rotation, which are noted in the Fuel Handling Log Book. The responsible engineer examines both seal alloy surfaces visually and by borescope on an average of every other full-molten mode. With few exceptions, both troughs are probed at several points during rotation of the plugs to determine how compacted the black powder has become. Sampling is done by brush cleaning at several locations to determine the amount of dross that has accumulated. The information obtained from observing plug rotation, from visual inspection, and from sampling is used to evaluate the necessity of cleaning one or both of the seal troughs. Cleaning is done in anticipation of sticking and not because of sticking.

As summarized in Table II, 2427 lb of dross has been removed from the large-plug trough, and 770 lb of dross has been removed from the small-plug trough. Two promising methods are being investigated for eliminating the formation of dross on the air sides of the freeze seals. One is to use

TABLE II. Summary of Trough Cleanings since October 1966

| Date of Cleaning | Large Plug | | Small Plug | | Date of Cleaning | Large Plug | | Small Plug | |
|---|---|---|---|---|---|---|---|---|---|
| | Dross Removed | Round Trips* | Dross Removed | Round Trips* | | Dross Removed | Round Trips* | Dross Removed | Round Trips* |
| 6/2-3/67 | 143 lb | 272 | | | 5/27-28/68 | 160 lb | 37 | | |
| 6/13-14/67 | | | 68 lb | 272 | 6/16-17/68 | 98 lb | 69 | 40 lb | 106 |
| 8/8/67 | | | 15 lb | 62 | 6/23-25/68 | 132 lb | 15 | | |
| 8/12/67 | 70 lb | 62 | | | 8/16-18/68 | 170 lb | 183 | 99 lb | 198 |
| 11/20-21/67 | 84 lb | 81 | | | 10/23-25/68 | 415 lb | 172 | 179 lb | 172 |
| 12/15-16/67 | 245 lb | 12 | 81 lb | 93 | 4/1-5/69 | 657 lb | 168 | 138 lb | 168 |
| 3/22-25/68 | 171 lb | 114 | 150 lb | 114 | 5/24/69 | 82 lb | 84 | | |

*This is the number of round-trip transfers before the seal cleaning. A round-trip transfer is the removal and replacement of a subassembly for the reactor core.

an inert blanketing medium over the alloy on the outer sides of the troughs. The other is to add approximately 1 wt % indium to the seal alloy.

### C. Recent Minor Problems

Even with the diligent inspection and brush cleaning of dross from the troughs of the freeze seals, several incidents of minor plug sticking have occurred. These are summarized below.

1. August 8, 1967 (small plug)

Sticking was attributed to binding of a support channel for a Teflon seal and to a localized concentration of dross. Fifteen pounds of dross was removed by brush cleaning. Fourteen hours were spent diagnosing the problem and cleaning.

2. September 18, 1967 (small plug)

After sticking occurred, the small-plug seal-molten control temperature was lowered from 480 to 380°F and allowed to "soak" for 2 hr. The small plug was then rotated 360° and back to operate with no signs of sticking. The amount of time lost was approximately 7 hr.

3. December 15, 1967 (large plug).

Seven hours were lost in this incident of which 5 hr were due to electronic malfunctions and 2 hr were spent in obtaining proper Variac settings. The large plug was then rotated freely 360° and back to operate. Both troughs were then brush-cleaned.

4. January 15, 1968 (small plug)

This sticking incident is attributed either to the cover $\Delta T$ being lower than normal or to the accidental opening of cooling-air dampers during maintenance of the core gripper and holddown. The amount of time lost was approximately 6 hr.

5. March 29, 1969 (large plug)

Sticking of the large plug was caused by accidental disconnection of a section of heaters. Immediately after reconnection of the heaters, the large plug rotated without difficulty.

Considerable progress has been made toward eliminating the troublesome sticking of the large and small plugs. Several minor sticking incidents have occurred, but were resolved by rotating the plug back and forth in a "jogging" fashion. These minor occurrences (minor in the sense that mechanical-force assistance was not used) were attributed to localized frozen spots in the seal alloy. The seal-temperature-control modifications and heater improvements described below have lessened these difficulties. During recent maintenance of the small-plug drive motor, the drive gear slipped on the motor shaft until it rested against a 1-in.-wide stiffener web. Continued rotation of the gear had cut approximately 1/4 in. into the web. The interference between the gear and web explains a number of anomalous sticking incidents which occurred with the small plug and were previously attributed to frozen spots in the seal alloy.

D. Changes to Temperature-control System

Several changes were made to the temperature control and heat input in the seal troughs during January 1968.

The section temperature controllers for the large and small plugs were altered. The original half-molten controllers, which sensed temperature through trough thermocouples, were stripped of their control function and now are temperature indicators only. The original full-molten controllers, which sensed temperature through blade thermocouples, now control both the full-molten mode and the half-molten mode. Changing control to the blade thermocouples has improved temperature control of the half-molten mode, because the blade thermocouples are not affected by dross buildup. The dross tends to insulate the trough thermocouples from the alloy, causing the indicated temperature to read lower than the actual alloy temperature.

The molten-control temperature for both plugs has been lowered in steps from 380 to 350°F. Both freeze seals have operated satisfactorily at temperatures as low as 320°F. The purpose of lowering the molten-control temperature is threefold: The time required to reach the seal-molten operating temperature has been reduced; the rate of dross formation will be reduced, which in turn lengthens the intervals between cleaning operations; and the possibility of corrosion of the trough and blade by the seal alloy will be reduced.

To reduce the seal-heat input and improve the operating conditions of the seal heaters, the lower-heater Variac setting has been reduced from 80 to 65%. The lower-heater Variac supplies power to the lower heaters of the large and small plugs.

## VII. CONCLUSIONS

EBR-II uses a fusible-alloy seal for positive containment of the primary-tank argon atmosphere and for allowing movement of the rotating plugs. This basic concept has been successfully demonstrated.

Admittedly, the operating difficulties with the rotating-plug freeze seals were one of the major problems with the initial EBR-II fuel-handling equipment. These difficulties have now been largely eliminated, through the knowledge and experience gained in correcting malfunctions of the freeze seals. As of mid-August 1969, 1364 subassemblies had been removed and a like number of subassemblies replaced in the reactor.

A development program to further improve the operating performance of the seals is in progress. This program is primarily a redesign of the existing freeze-seal temperature-control system, whose operating performance is marginal. The improved temperature-control system is expected to eliminate sticking of the rotating plugs caused by cold spots in the seal alloy. The improved system is also expected to permit lowering the operating temperatures of the seal alloy, thus decreasing the rate of dross formation.

We conclude that a fusible-alloy seal can be reliably used to contain an inert-gas atmosphere while allowing rotational movement of rotating shields.

## REFERENCES

1. L. J. Koch, H. O. Monson, D. Okrent, M. Levenson, W. R. Simmons, J. R. Humphreys, J. Haugsnes, V. Z. Jankus, and W. B. Loewenstein, Hazard Summary Report: Experimental Breeder Reactor II (EBR-II), ANL-5719 (May 1957).
2. L. J. Koch, W. B. Loewenstein, and H. O. Monson, Addendum to Hazard Summary Report: Experimental Breeder Reactor-II (EBR-II), ANL-5719 (Addendum) (June 1962).
3. C. C. Crothers, An Investigation of Metallurgical Problems Associated with the EBR-II Fusible Seals, ANL-7589 (Sept 1969).
4. D. E. Mahagin, An Investigation of Segregation in the Bismuth-Tin Eutectic Alloy, a thesis for the degree of Master of Science in Metallurgical Engineering at the University of Idaho Graduate School (1965).
5. Reactor Development Program Progress Report: July 1965, ANL-7082, p. 2.
6. Reactor Development Program Progress Report: September 1965, ANL-7105, p. 2.

Admittedly, the operating difficulties with the rotating-plug freeze seals were one of the major problems with the initial EBR-II fuel-handling equipment. These difficulties have now been largely eliminated, through the knowledge and experience gained in correcting malfunctions of the freeze seals. As of mid-August 1969, 1504 subassemblies had been removed and a like number of subassemblies replaced in the reactor.

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## REFERENCES


1. L. J. Koch, H. O. Monson, D. Okrent, M. Levenson, W. R. Simmons, J. R. Humphreys, J. Haugsnes, V. Z. Jankus, and W. B. Loewenstein, Hazard Summary Report, Experimental Breeder Reactor II (EBR-II), ANL-5719 (May 1957).

2. L. J. Koch, W. B. Loewenstein, and H. O. Monson, Addendum to Hazard Summary Report, Experimental Breeder Reactor II (EBR-II), ANL-5719 (Addendum) (June 1962).

3. C. C. Crothers, An Investigation of Metallurgical Problems Associated with the EBR-II Fusible Seals, ANL-7569 (Sept 1969).

4. D. F. Mahagin, An Investigation of Segregation in the Bismuth-Tin Eutectic Alloy, a thesis for the degree of Master of Science in Metallurgical Engineering at the University of Idaho Graduate School (1965).

5. Reactor Development Program Progress Report, July 1965, ANL-7082, p. 2.

6. Reactor Development Program Progress Report, September 1965, ANL-7105, p. 2.